Using WSJT-X for Microwave EME (Q65 and Echo mode)

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Based on EME2022 presentation

Update #3 (7 Dec 2022)

Agenda

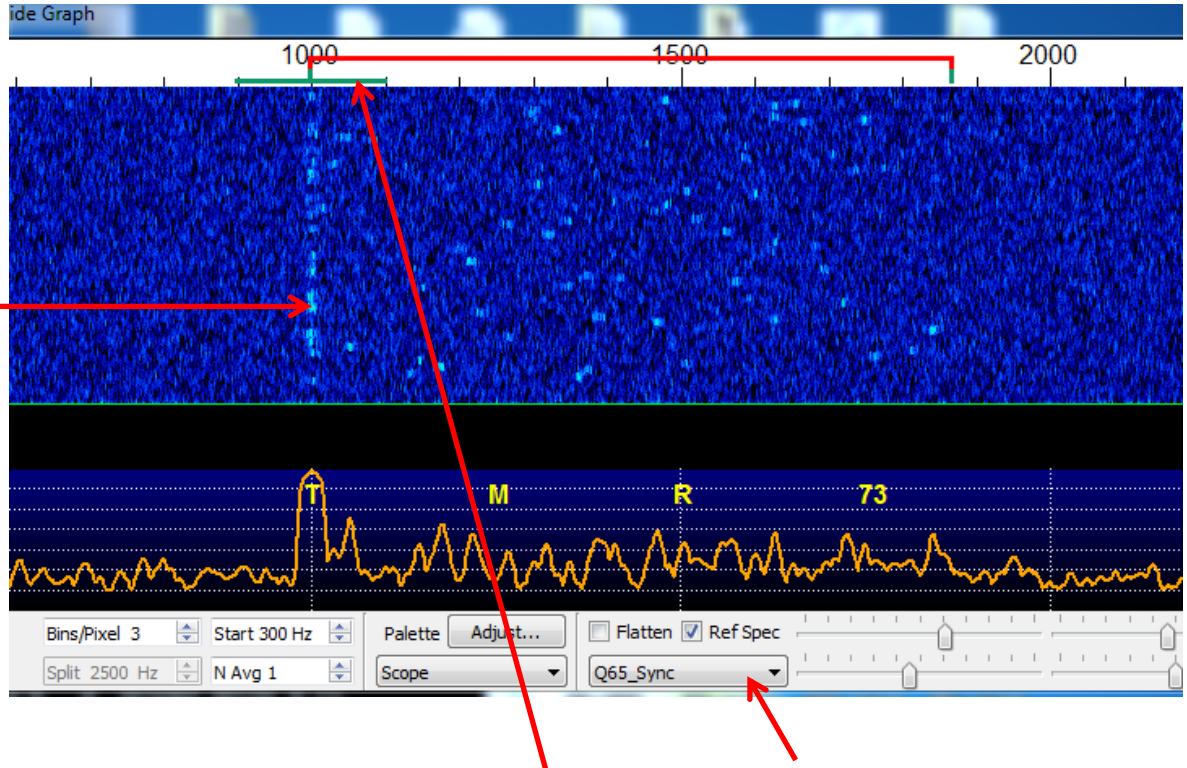
- Q65 features
- Choice of optimum sub-mode and decoding options
- Signal on waterfall, but no decode – why?
- Getting the best out of Q65-60E for 10GHz and above
- New Echo mode
- Doppler compensation, and advantages of CFOM
- Determining S/N margin of a signal
- Drift compensation, non-standard callsigns and decoding the full passband
- Appendix: delayed decoding, signal report accuracy, polynomial, q65sim, references , latest features

Q65

- Replaces QRA64 (since 2021)
- **Sync tone more easily visible on waterfall**
- Powerful algorithm to deal with high Doppler spread
- Does not use a callsign database
- Practically immune from false decodes
- **Includes Averaging and Auto-Sequencing**
- **Improved sensitivity**
- **A variety of period lengths and tone spacings**
- **Optional ability to decode whole passband**
- **Ability to decode drifting signals**
- **Allows use of non-standard callsigns, with same sensitivity as standard callsigns**

What does a Q65 signal look like?

Q65-60D, Tx=1000Hz (S/N = -15dB/2500Hz, spread=25Hz)



Sync Tone

Q65 sync plot

Green bar centred on Rx frequency, width set by Ftol. Decoding is attempted on signals within width of green bar. If signal is too weak to see on waterfall, and you are not sure of frequency, then a wide Ftol should be used (at the expense of decode time and possible loss of sensitivity). In most cases start with 100Hz, but experimenting may prove useful in some cases.

Q65 sub-modes

<u>The letter designator does not indicate a particular tone spacing</u>.

T/R Period (s)	A Spacing (Hz)	A Width (Hz)	B Spacing (Hz)	B Width (Hz)	C Spacing (Hz)	C Width (Hz)	D Spacing (Hz)	D Width (Hz)	E Spacing (Hz)	E Width (Hz)
15	6.67	433	13.33	867	26.67	1733	N/A		N/A	
30	3.33	217	6.67	433	13.33	867	26.67	1733	N/A	
60	1.67	108	3.33	217	6.67	433	13.33	867	26.67	1733
120	0.75	49	1.50	98	3.00	195	6.00	390	12.00	780
300	0.29	19	0.58	38	1.16	75	2.31	150	4.63	301

Note: T/R period 15s does not work with EME time delay!

Choice of sub-mode

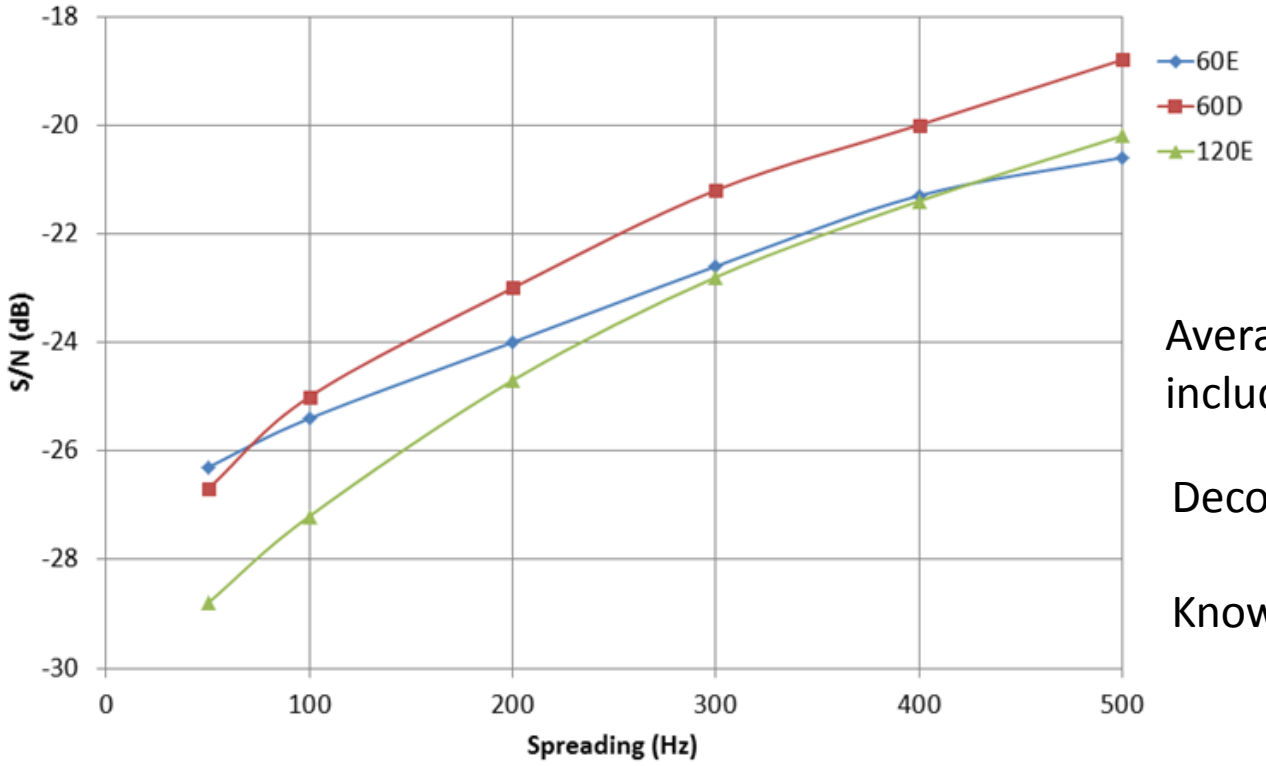
- Longer period lengths increase sensitivity
- But, the narrower tone spacing associated with longer period lengths can reduce sensitivity if Doppler spread is too high more than the gain in using a longer period.

Commonly used sub-modes:

1.3-3.4GHz	60C
5.7GHz	60D
10GHz	60D and 60E (DL0SHF beacon uses 60E)
24-47GHz	60E

Feel free to experiment! A QSO may sometimes be possible by using another sub-mode.

S/N for 50% decoding success v spreading



Average decodes included

Decode = Deep

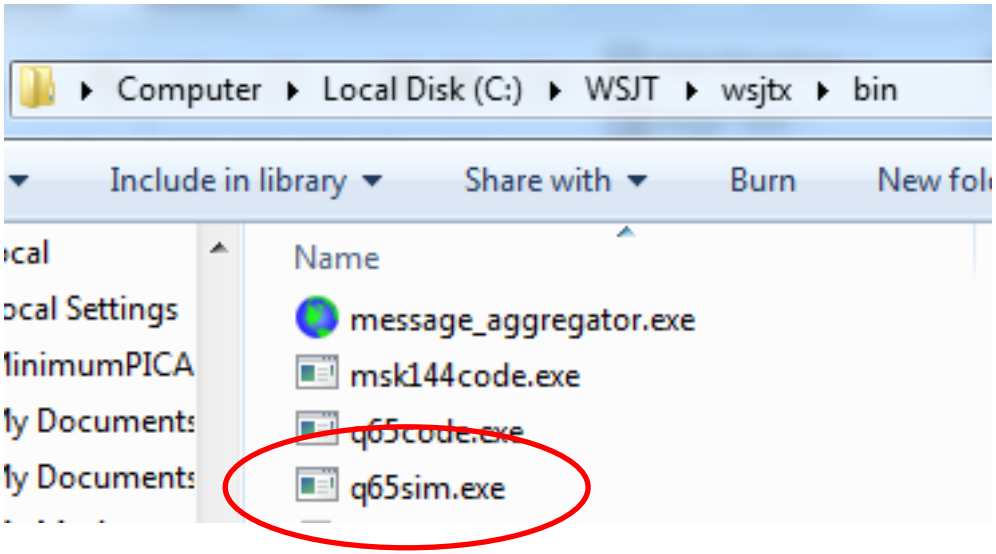
Known callsigns

This graph allows optimum choice of sub-mode for different spreading conditions. For example, at 100Hz spreading 120E would be the best mode, followed by 60E, which is slightly better than 60D. At 500Hz, 60E is slightly better than 120E, and 60D would perform worst.

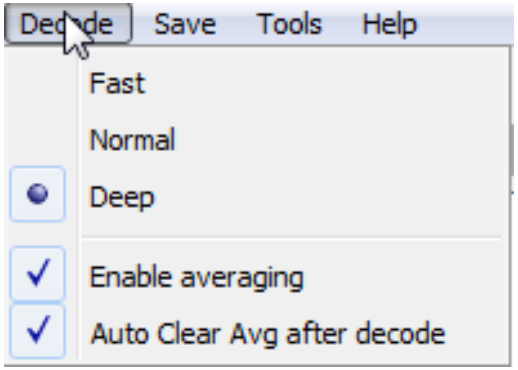
Note for 10GHz ops: At all spreading values above 70Hz , 60E outperforms 60D!

What about other sub-modes?

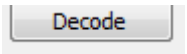
q65sim.exe is a tool that allows wave files to be generated at any desired Doppler spread and any S/N, with drift and Doppler steps included, so anyone can experiment! Please refer to Appendix for more information.



Decoding Options



Fast, Normal and Deep options are available. Fast will decode most signals; for very weak signals Deep may be needed, but the decoding process will generally take longer.

Note: If a decode is not obtained in real time with Fast, double clicking on the sync tone frequency on the waterfall (or pressing 

) will invoke a second decoding attempt using Deep automatically.

Increased decode sensitivity using AP

- AP (a-priori) decoding improves sensitivity by up to 4dB
- Decode text shows what type of AP was in use
- AP makes use of any already known information, eg DX Call and grid locator, to assist the decoder.

Table 6. Q65 end-of-line codes

qP	Message components
q0	? ? ?
q1	CQ ? ?
q2	MyCall ? ?
q3	MyCall DxCall ?
q4	MyCall DxCall [<blank> | RRR | RR73 | 73]
q5	MyCall DxCall ? (**Max Drift** = 50)

? Indicates that message component was unknown to the decoder. Exception to this is MyCall DxCall DxGrid (Tx 1) message, where DxGrid is used as AP information, if available

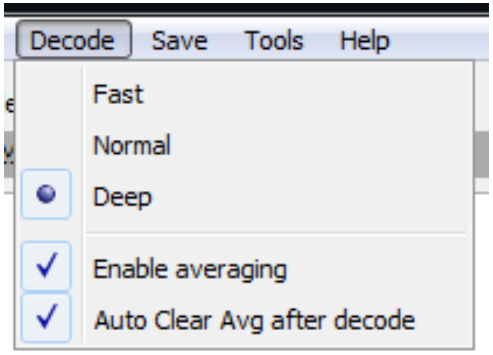
Optimum use of AP

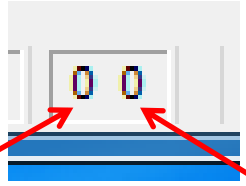
- For a sked, or when calling a known station, ensure that DxCall and DxGrid are filled in for the station you want to work. [Double clicking a decoded message will populate these fields automatically].
- When monitoring a marginal station in QSO, temporarily change MyCall to that of the station being called by the station you are monitoring and enter the station you are monitoring into DxCall and DxGrid. Remember to revert to your own call afterwards before transmitting, to avoid being a pirate!

Note: When entering Settings to change MyCall, the sked frequency will probably change and you will need to reset it!!

Using Averaging to decode very weak signals

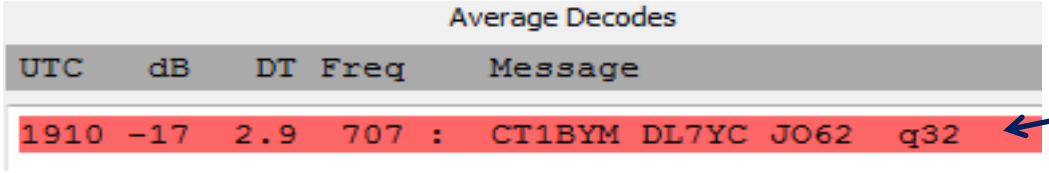
Q65 is often able to decode very weak signals by accumulating information from several (identical) messages. The last 4 messages have equal ‘weight’ – earlier messages have a decreasing contribution according to their ‘age’. Even and odd periods are stored in separate accumulators, and the number of messages stored in each is shown in the box at the bottom of mainwindow. Pressing Clear Avg resets the even and odd period accumulators.





Even period counter

Odd period counter



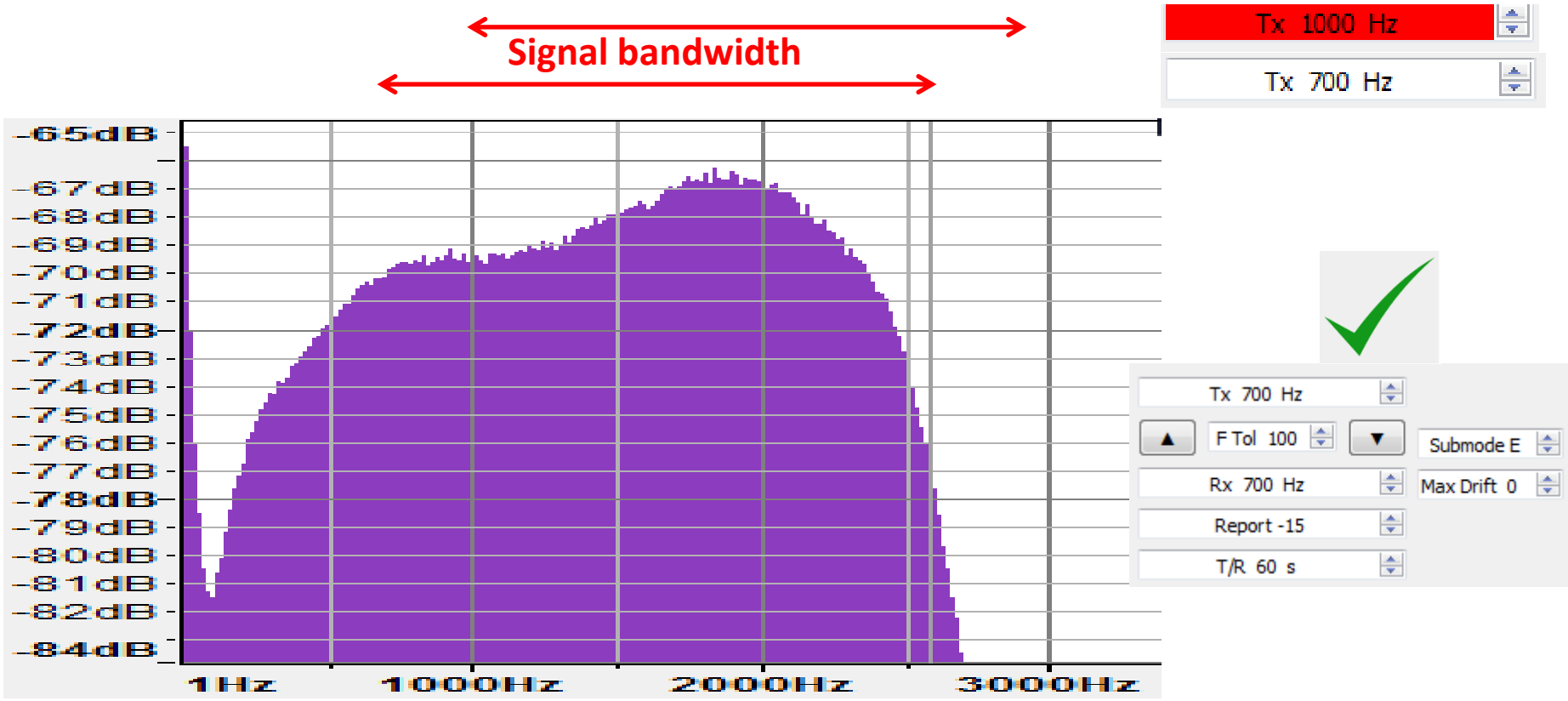
q3 type decode from 2 messages

- For normal operation, and in almost all cases on microwave bands, this should be selected as shown above.
- If not selected, additional decodes may appear subsequently that do not relate to incoming messages. Even noise input can trigger such decodes, since the message stored in the average accumulator still has sufficient S/N to allow decoding!
- The only situation where it should not checked is for a DXpedition station , who wishes to accumulate the average from multiple callers to be able to click on Q65 sync peaks of the different callers to try to decode them in preparation for calling them.

See the signal on waterfall , but no decode?

- Are you using the same sub-mode as your QSO partner?
- Message changed during the period?
- Station started transmitting too late?
- Signal is drifting or unstable?
- PC time is not correct?
- PC Time was corrected during a period (Dimension4)?
- Try Deep decode (if using Fast initially)
- Audio dropout (close and restart WSJT-X)?
- Large Doppler step (eg 20Hz) occurred near middle of period?
- Or, more than one contributing factor!!

Q65-60E on a real rig

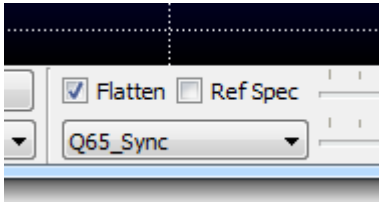


Limitations in the upper edge of the passband can sometimes be compensated, for by driving one or more stages of the RF stages in the TX chain into compression. **This should not be done at audio, to avoid distortion products**!

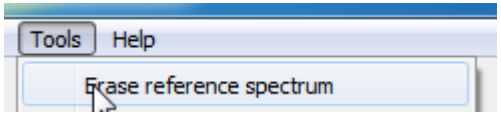
Use of reference spectrum

- Use of reference spectrum flattens the audio response of your receive system. It can even be of benefit with SDRs.
- In some cases, use of Ref Spec may increase the available audio bandwidth on receive.
- Under some circumstances, decoding of very weak signals can be improved.
- Signal to noise ratio accuracy of decodes may be improved.
- Allows Echo mode to find weak widely spread signals more effectively

Reference spectrum procedure



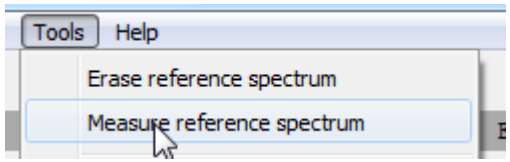
Must have Flatten checked
before starting



Click this

Point antenna off moon, or tune to a perfectly quiet frequency with no birdies.
Set receiver to how you normally use it (IF bandwidth, gain, passband tuning, noise blanker [if used, best not to use] etc etc).

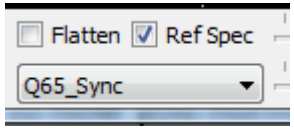
Reference spectrum procedure - contd



Click this

Wait 60s, or more

Click this

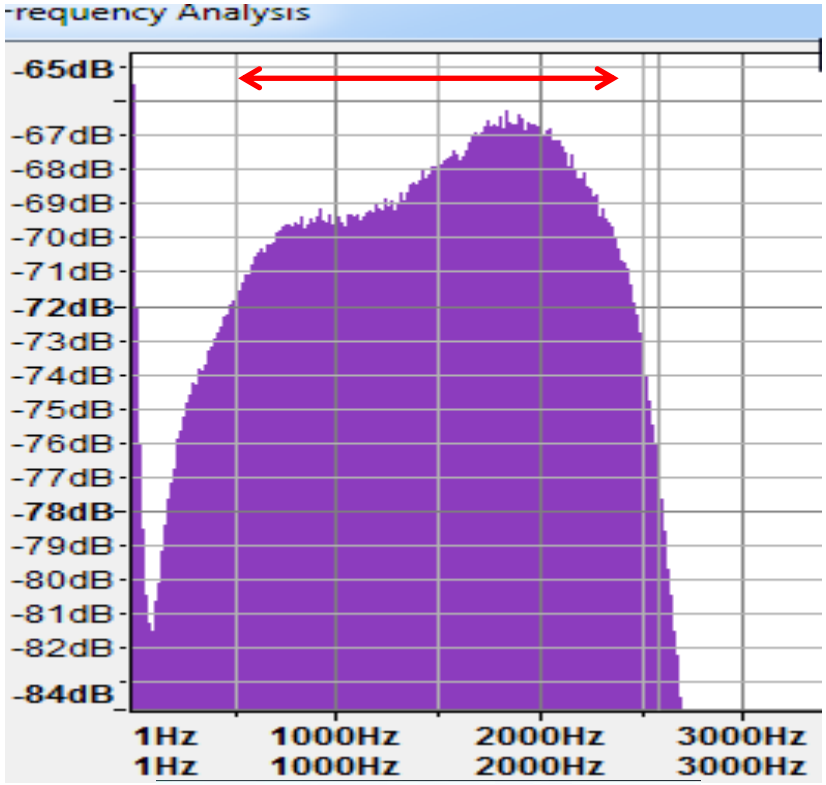


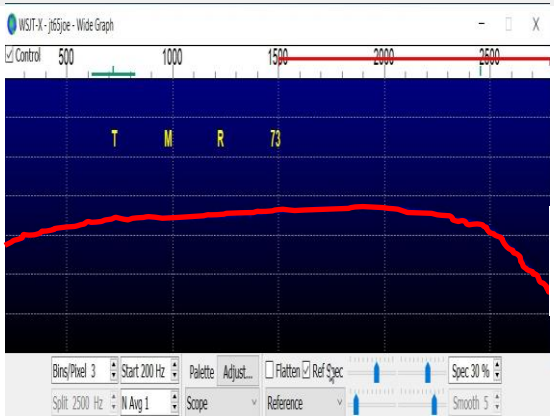
Select Ref Spec

If any changes are then made to receiver settings the procedure must be repeated. It is a good idea to record a new reference spectrum periodically.

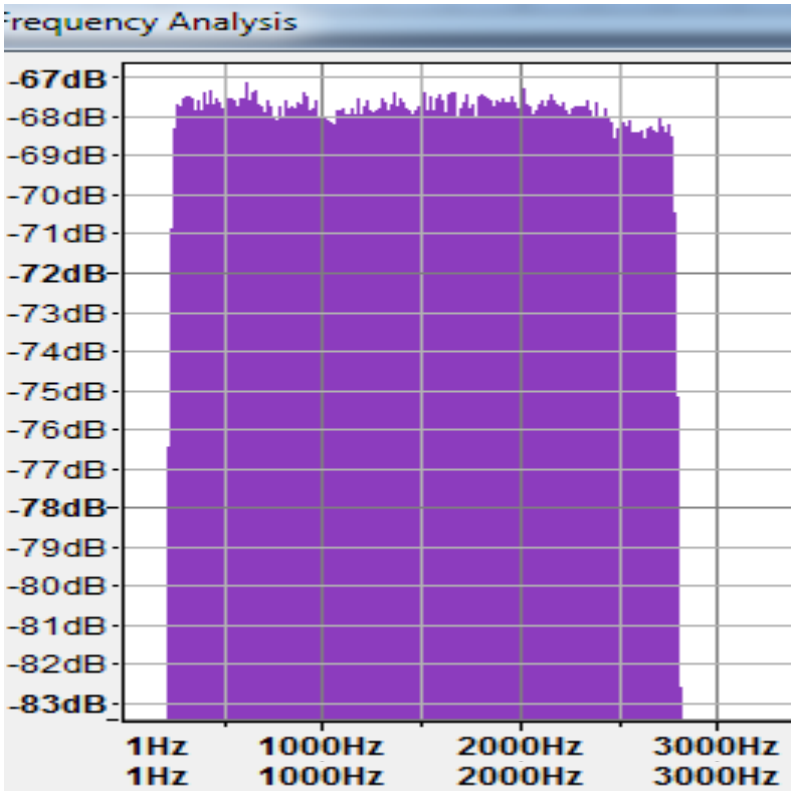
Example of use of Ref Spec

Using Flatten





Using Ref Spec



Q65-60E bandwidth

Your audio passband can be displayed (for interest) by temporarily selecting Reference on the waterfall display.

Revised Echo Mode (2.6.0-rc4)

- WSJT-X 2.6 introduced a revised version of the Echo mode. In the past, Echo presented just a peak value for S/N which did not allow for Doppler spread. **This new version integrates the signal power over the bandwidth of a spread signal, thus presenting a much more accurate estimate of S/N for signals with significant spreading**.
- In addition to generating and receiving your own echoes, the program can be used in 'Monitor' mode to measure the S/N of someone else's signal, below the level at which Q65 decodes can be obtained.
- Both normal and Monitor mode require the signal to be at 1500Hz [+/- 10Hz]. This requires appropriate Doppler compensation to be used, and very accurate frequency calibration if monitoring another station.
- Applications include system assessment and optimisation, and comparison with other stations. Agreement with VK3UM EMECalc has been shown to be very good.

Interpreting the text output

File Configurations View Mode Decode Save Tools Help

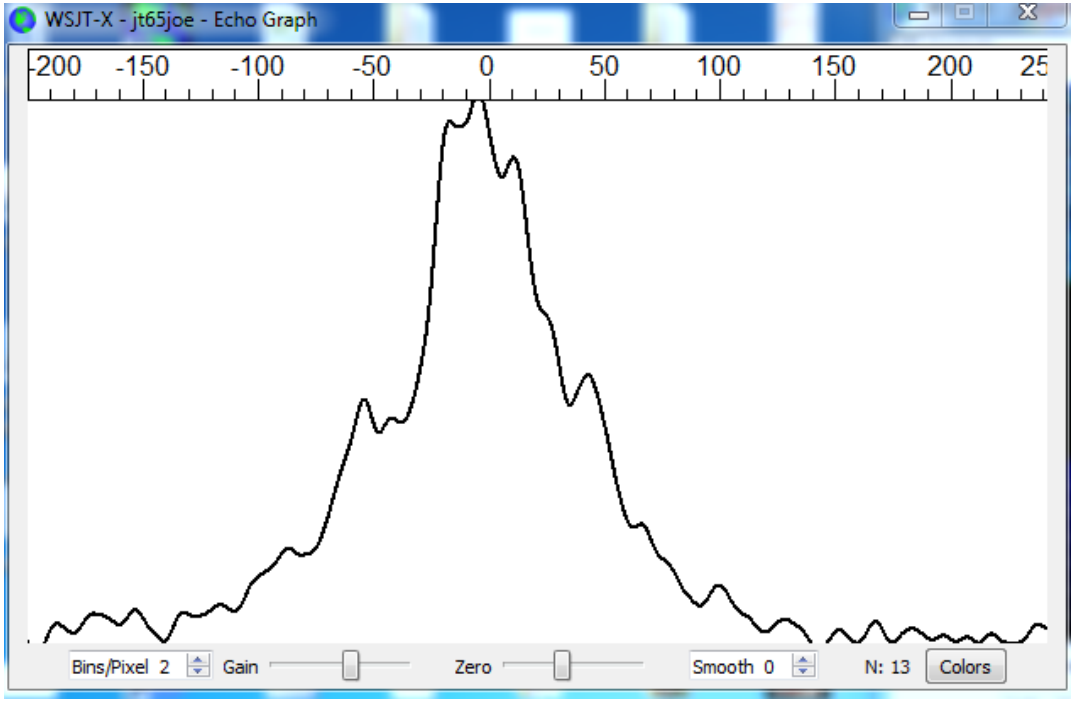
UTC	Tsec	Level	Doppler	Width	N	Q	DF	SNR	dBerr
022845	0	54.53	591	18.5	1	10	0	-8.9	0.5
022851	6	54.61	590	18.5	2	10	0	-8.4	0.5
022857	12	54.36	589	18.5	3	10	-2	-9.0	0.5
022903	18	54.49	588	18.5	4	10	-2	-8.7	0.5
022909	24	54.27	587	18.5	5	10	-2	-9.0	0.5
022915	30	54.67	586	18.5	6	10	-1	-8.3	0.5
022921	36	54.66	585	18.5	7	10	-1	-8.1	0.5
022927	42	54.76	584	18.5	8	10	-1	-7.8	0.5
022933	48	54.66	583	18.5	9	10	-1	-7.7	0.5
022939	54	54.42	581	18.5	10	10	-1	-7.8	0.5

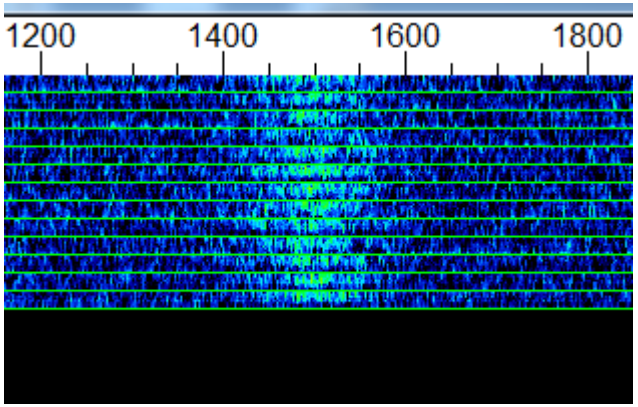
UTC: UTC
Tsec Number of seconds elapsed since starting echo sequence
Level: Audio level (same as thermometer on mainwindow)
Doppler: Doppler shift of echo (calculated value from Astro) [Hz]
Width: Signal width (calculated value from Astro) [Hz]
N: Number of echo (or monitor) cycles
Q: Estimate of quality of the data [integer number from 0 to 10]
DF: Distance of signal peak from 1500Hz [Hz]
SNR: Signal to noise ratio [dB/2500Hz]
dBerr: Estimate of error in S/N value

Use of Echo mode for self echoes

- It is used in just the same way as the prior version, as explained in section 8.6 of the WSJT-X User Guide.
- Sufficient echo cycles should be used until the S/N and dBerr settle to stable values, as shown in the on-screen text. [It is likely that the first few echoes will show a higher S/N than reality due to libration peaks; this is normal and these early results should be ignored]. How many echo cycles are needed depends on S/N and spreading (more for weaker signals and wider spreading).
- The echo is also shown in the Echo graph. You will see that it becomes less ‘noisy’ as the average builds up.

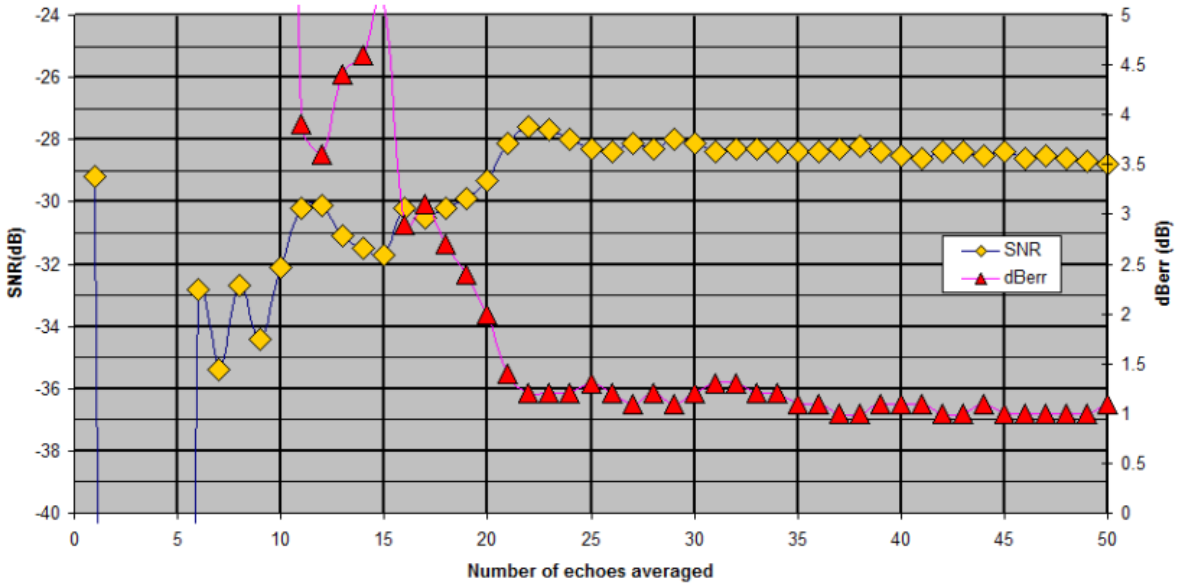
Echo graph and waterfall





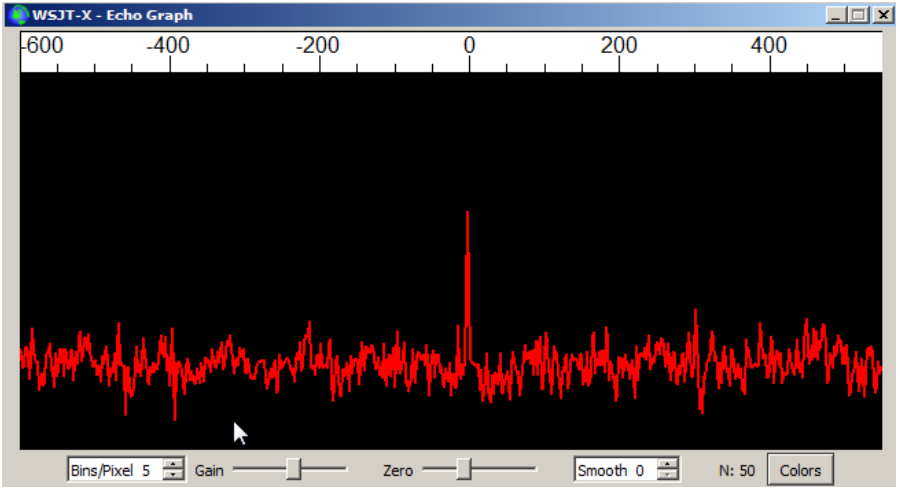
System: 2.4m dish, 70W at feed. Spread = 221Hz

KA1GT Echoes at 1296 (through dense trees)



S/N

dBerr

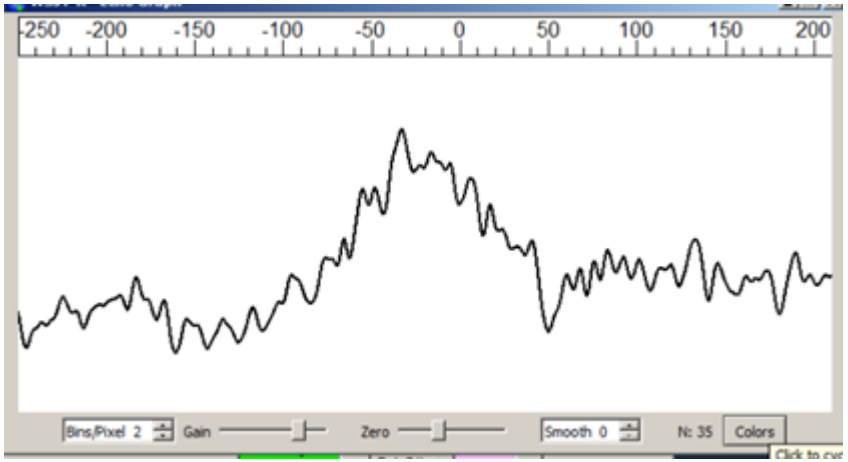


KA1GT running 240W to 3.1m dish. Moon was not visible by eye through the trees.
With moon in the clear, echoes are about –9dB. From this, the trees are costing nearly 20dB!

Echo - Monitor mode

- This is used to measure S/N of another station. If the mutual Doppler shift is >750Hz, appropriate Doppler correction must be applied . When you know that the other station has started transmitting, press Monitor button and the data will start to accumulate. If Monitor is green when Echo mode is selected, press 'Clear Avg' button when the other station starts transmitting. Previous accumulated data can be erased by pressing Clear Avg button. Pressing Erase only clears the text, not the accumulated data.
- Transmitting a 1500Hz tone is most easily achieved by the transmitting station selecting Echo Mode, Doppler method 'Own Echo' and pressing the 'Tune' button.

Example of monitor mode

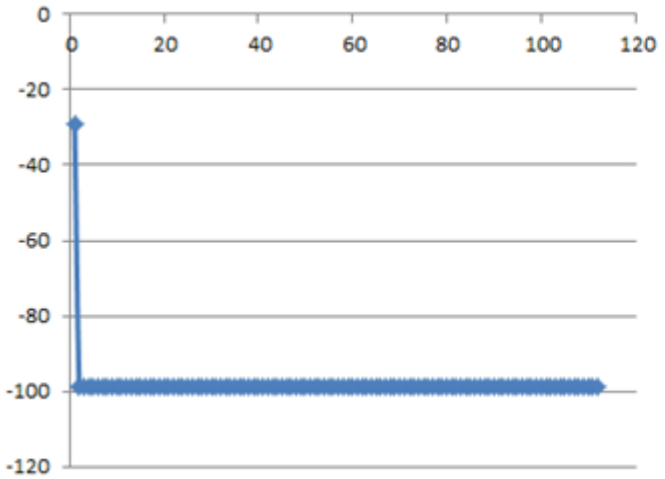


UTC	N	Level	SNR	dBerr	DF	Width	Q
19:42:53	17	52.7	-22.1	0.7	-31.1	96.9	5
19:42:56	18	52.8	-22.5	0.7	-29.3	96.9	4
19:42:59	19	52.7	-22.2	0.7	-31.1	96.9	5
19:43:02	20	52.9	-22.2	0.6	-29.3	97.0	5
19:43:05	21	52.6	-21.7	0.6	-29.3	97.0	6
19:43:08	22	52.8	-21.6	0.5	-29.3	97.0	6
19:43:11	23	52.7	-21.7	0.5	-29.3	97.1	6
19:43:14	24	52.7	-21.6	0.5	-29.3	97.1	6
19:43:17	25	52.7	-21.8	0.5	-29.3	97.1	6
19:43:20	26	52.7	-21.8	0.5	-29.3	97.2	6
19:43:23	27	52.7	-21.7	0.5	-28.9	97.2	7
19:43:26	28	52.8	-21.7	0.5	-28.9	97.3	7
19:43:29	29	52.8	-21.7	0.5	-28.9	97.3	7
19:43:32	30	52.7	-21.8	0.5	-28.9	97.3	7
19:43:35	31	52.6	-21.8	0.5	-22.3	97.4	7
19:43:38	32	52.7	-21.9	0.5	-22.3	97.4	7
19:43:41	33	52.7	-21.9	0.5	-21.2	97.5	7
19:43:44	34	52.7	-22.0	0.5	-21.2	97.5	7
19:43:47	35	52.7	-21.9	0.5	-21.2	97.5	7

Stop | Monitor | Erase | Decode

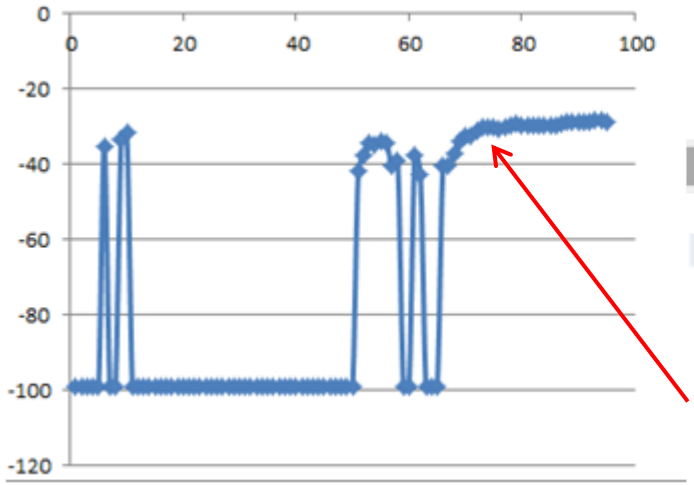
KA1GT (80cm dish) receiving DL3WDG (1.2m/70W on 10GHz)

47GHz examples (plots of SNR v cycles)



No signal detected (DL7YC->W5LUA)

UTC	N	Level	SNR	dBerr	DF	Width	Q
#######	90	61.1	-99	99	209.1	400	0



Barely detectable signal(DL7YC->W5LUA)

UTC	N	Level	SNR	dBerr	DF	Width	Q
#######	95	60.9	-28.6	3.3	209.8	400	0

Stable result after this point

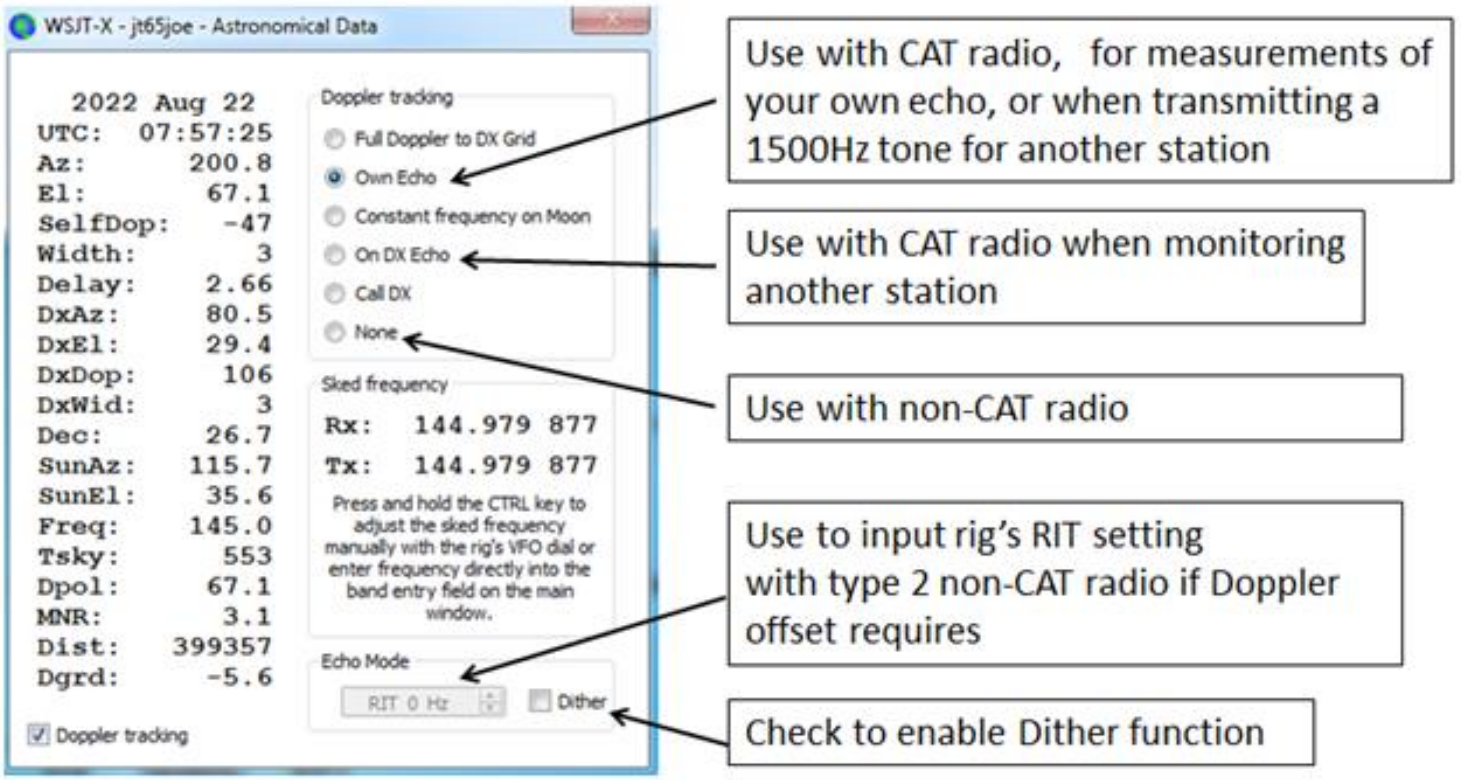
Note: This method outperforms Linear Avg waterfall spectrum for detection of very weak signals with wide spreading.

Echo mode in WSJT-X 2.6 –rc5

- Optional audio tracking of Doppler*
- Does not require a CAT compatible radio!
- Works in self echo and monitor mode
- Saves wave files, which can be played back later.

* May also work better than CAT control if your radio has significant delays processing CAT commands, which can shorten the TX pulse.

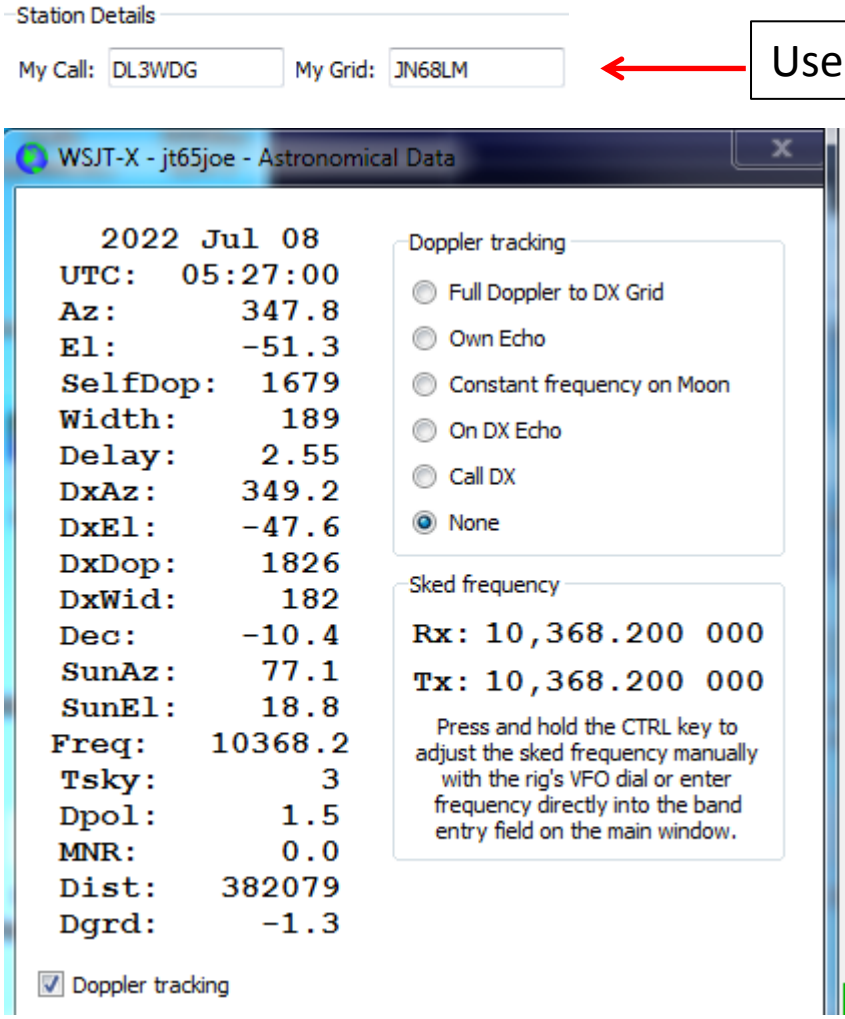
Doppler settings for Echo Mode

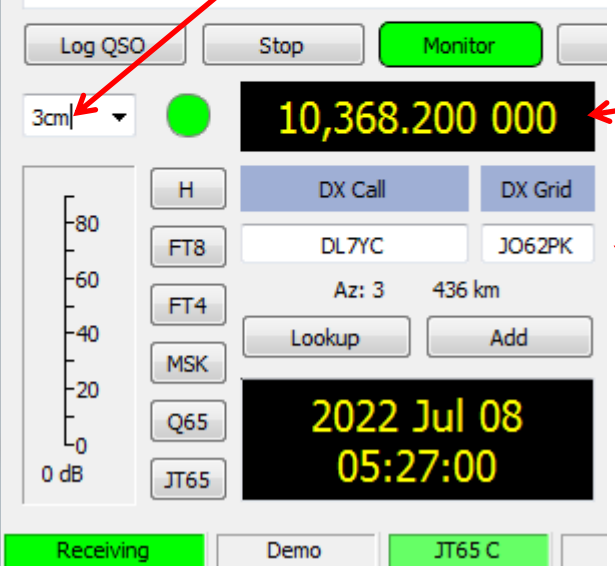


Note: A 'type 2 non-CAT radio' has ability to set RIT by a known, precise, amount to bring received signal close to 1500Hz.

Automated Doppler Compensation

Requires a Computer Assisted Transceiver (CAT) compatible radio





Use full 6 character grid for highest accuracy!

Can set sked freq here by typing in the kHz offset from band edge. For example, to tune to 10368.024, type 24k in the box.

Rig is CAT tuned to frequency shown here

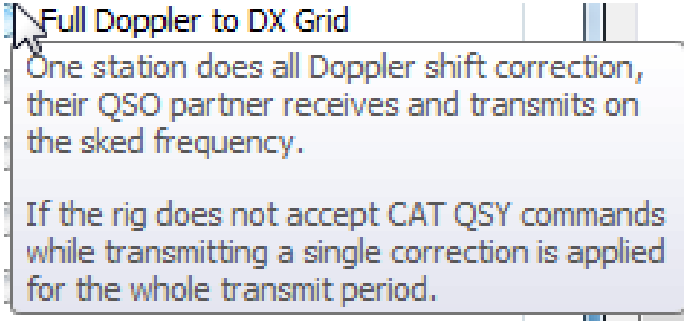
Use full 6 character grid for highest accuracy!

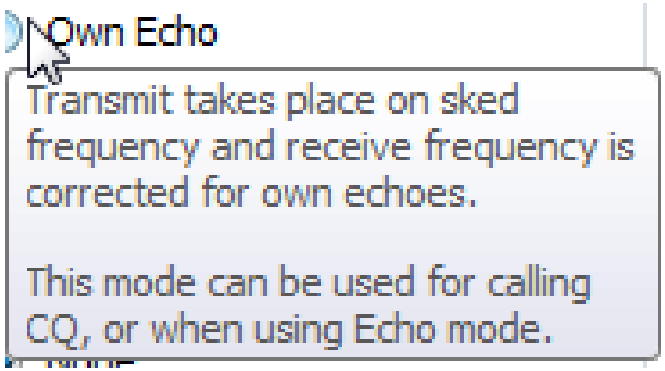
Doppler modes in WSJT-X

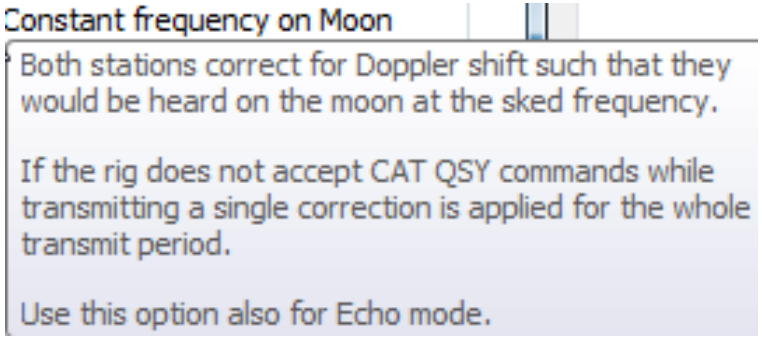
Doppler modes in WSJT-X		25-Jan-18				
Method	Name	RX shift	TX Shift	Tracking	rb names	Note
0	None	none	none		NoDoppler	
1	Full Doppler to DX Grid	m_dop	-m_dop	yes	FullTrack	
2	Constant Freq on Moon	(m_dop00)/2	-(m_dop00)/2	yes	ConstFreqOnMoon	
3	Own Echo	m_dop00	none	yes	OwnEcho	
4	On DX Echo	m_dop	see below	yes	OnDxEcho	1
5	Call DX	none	-m_dop00	tx only	CallDx	
parameter names						
m_dop00	two way self Doppler					
m_dop	two way mutual Doppler					
m_dx_two_way_dop = 2 * (m_dop - (m_dop00/2))				DX station's two way self Doppler		
TX shift for OnDxEcho = m_dx_two_way_dop - m_dop						
Note 1	TX tracking is referenced to time when button is first pressed					
	(I think Bob's revision to the code changed this behaviour so it now tracks)					

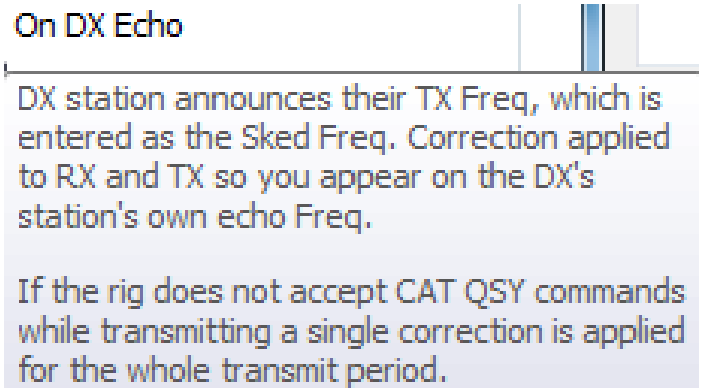
Note: Methods 1 and 4 only work if Grid locator for DX station is entered.

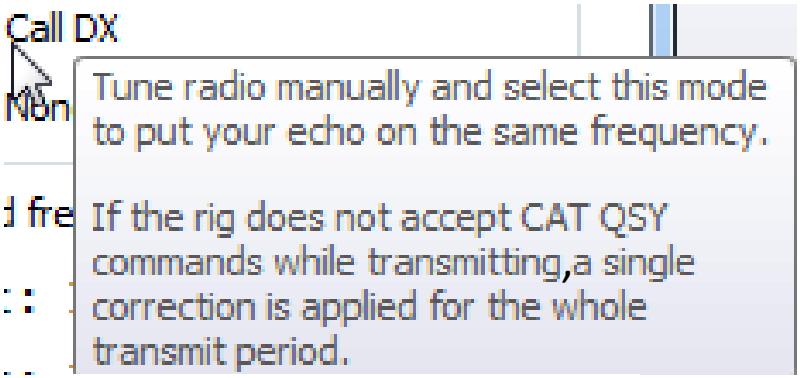
Doppler Method tool tips

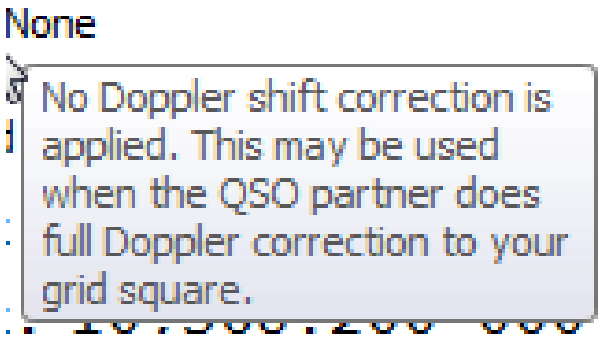












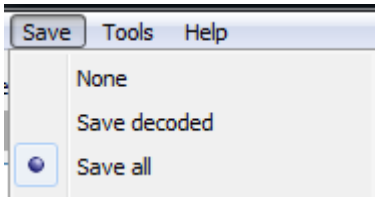
Advantages of CFOM

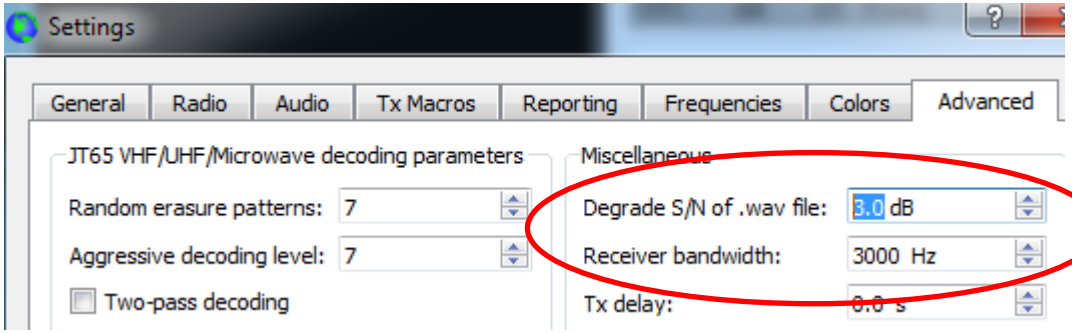
- No need to know DX station's location
- Own echoes are correctly tuned
- Partner's own echoes are correctly tuned
- You can monitor both stations in QSO
- Best mode for DXpeditions
- Ideal for random operation
- Usage is near 100% on higher bands, and increasing on lower bands

WSJT-X Degradation tool

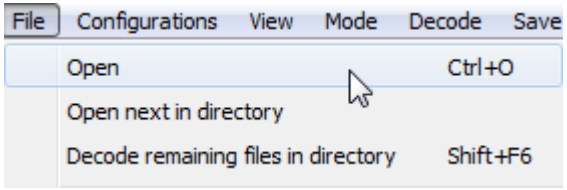
- Allows saved wave files to be decoded with added noise to investigate how much margin a given signal achieved.
- The amount of degradation can be adjusted until the signal stops decoding. [Note: near the margin, statistical variations in the noise may result in the signal sometimes decoding and other times not.]

Using the degradation tool





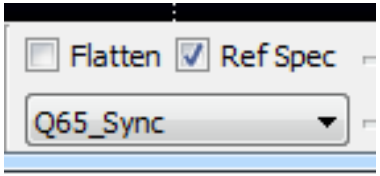
Set to your receiver audio bandwidth (important)



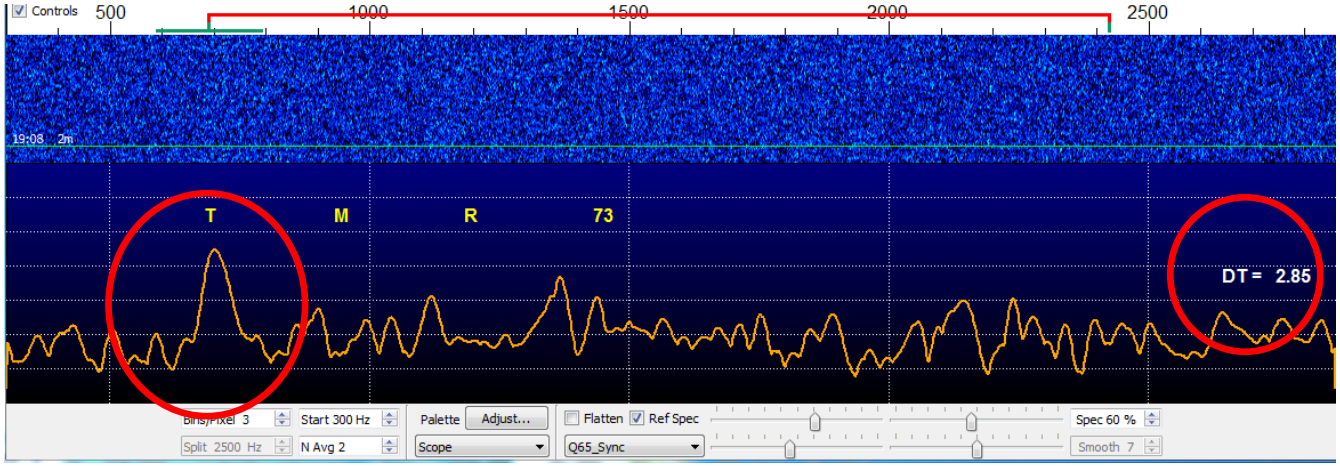
Navigate to where your wave files are stored.
[Save directory is shown in Settings->Audio]

Q65 sync plots

These are useful to display the likely presence of a signal, which is too weak to decode. They are most useful when unknown stations are calling. If full AP is in operation, decodes are often possible with little or no indication of a signal on the plots.

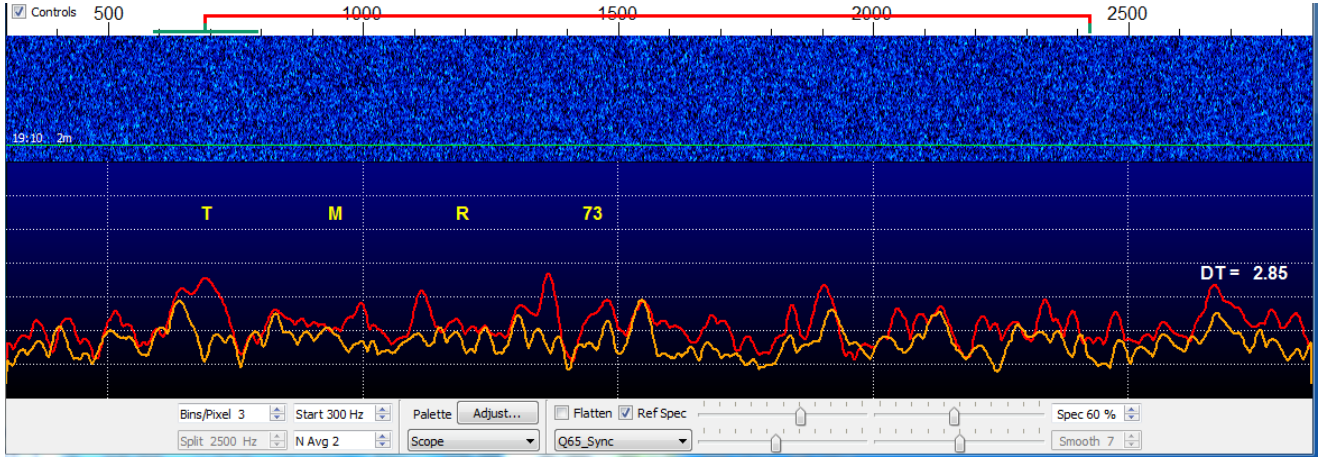


Examples of Q65 Sync plots (orange is single period, red is average)



File 1908

One period, no decode. Likely signal at 700Hz, with good DT



File 1910 added. Orange line shows result from file 1910 and red line shows files 1908 and 1910 averaged. The average decoded.

Drift compensation

- Linear frequency drift can be measured and compensated for using the Max Drift control. Normally, this should be set to 0 as shown below when signals are stable (eg with rigs locked to GPS and Doppler correction active).
- If the received signal is drifting and will not decode, a non-zero setting may be beneficial. Greatest benefit is with signals that are drifting by an amount in excess of the tone spacing during a period.

Non-standard callsigns

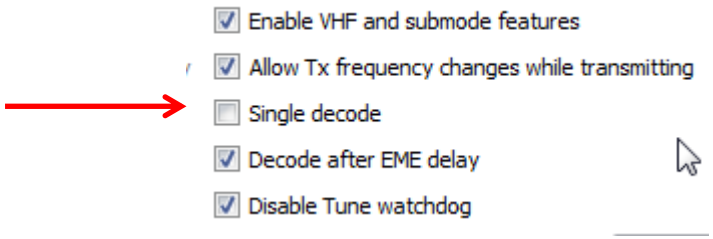
The latest versions of WSJT-X support the use of a non-standard callsign by one of the QSO partners, with full decoding sensitivity. Examples of a non standard callsign are HA/DL3WDG and PA100THALES. A model QSO using such a callsign is shown below:

```
CQ PJ4/K1ABC
                        <PJ4/K1ABC> W9XYZ
W9XYZ <PJ4/K1ABC> +03
                        <PJ4/K1ABC> W9XYZ R-08
<W9XYZ> PJ4/K1ABC RRR
                        PJ4/K1ABC <W9XYZ> 73
```

In every message one of the callsigns is sent as a “hash” code using a smaller number of bits, and is enclosed in <…> brackets. For the callsign to be displayed in full, the station’s callsign must either be present in the DX Call box, or has been decoded in full in the recent past. For further information, see section 7.5 in the WSJT-X User Guide.

Multi-decoding

Q65 has the ability to decode multiple signals in the audio passband automatically. To invoke this, uncheck Single decode in the Behavior part of General settings menu:

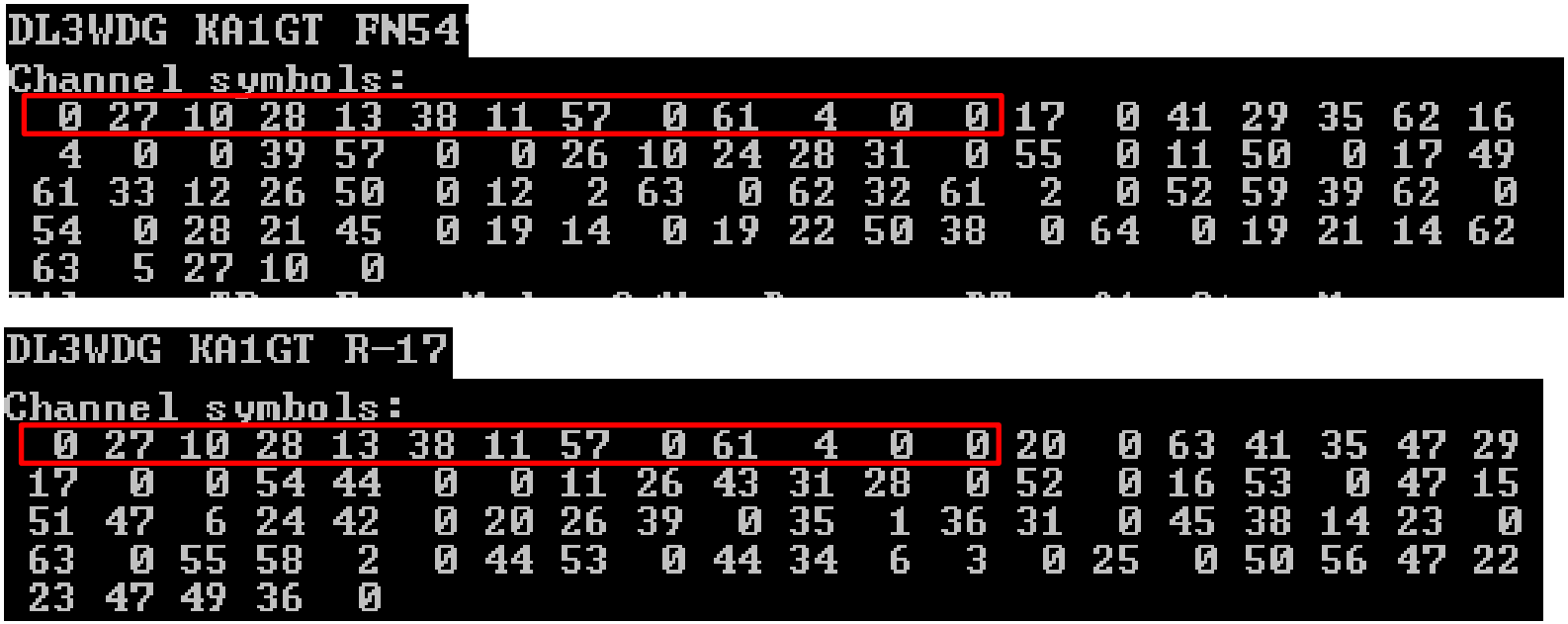


Decoding the whole passband increases decode time, and needs signals to have higher S/N, compared to single decoding.

Appendix

- Delayed decoding
- Signal report accuracy
- Polynomial coefficients of sensitivity v spreading chart
- Using q65sim.exe
- References

Does it matter if decoding continues into the following transmit period?



The first 13 characters of the two messages are identical. The time taken in a 60s period to transmit these characters is about 8s, meaning that if decoding is completed up to 8s into the following transmit period, the next transmitted message will not be 'corrupted'.

Even if decoding takes a few seconds longer, the robust error correction built into the protocol will ensure that the correct message is received (with slightly reduced S/N).

Long decoding time

Possible causes:

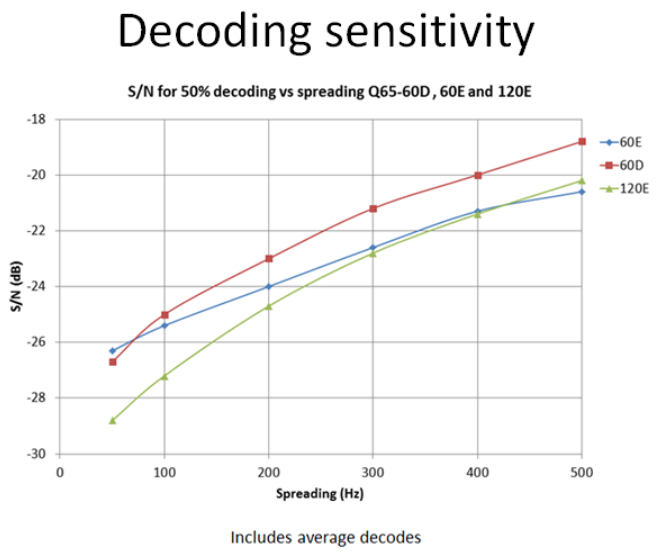
- Wide Ftol setting
- Single decode not selected
- Deep decoding setting used
- Slow PC

Signal report accuracy

- Signal reports are given as dB S/N in 2500Hz
- In most situations, the signal report is quite accurate.
- With wider bandwidth submodes (eg 60E), with Tx/Rx frequency = 700Hz, S/N can appear better than reality, dependent on your lower audio passband cutoff frequency. This does not affect ability to decode signals.
- Thus it is common for two stations with identical performance to see different S/N values for the same signal.

Equations for the Decoding sensitivity graph.

- 60D: $y = 5.6139E\text{-}08x^3 - 6.4781E\text{-}05x^2 + 3.7718E\text{-}02x - 2.8285E+01$
- 60E: $y = -2.68935E\text{-}08x^3 + 1.16662E\text{-}05x^2 + 0.013908449x - 27.00821099$
- 120E: $y = 0.00000x^3 - 0.00005x^2 + 0.03874x - 30.75116$

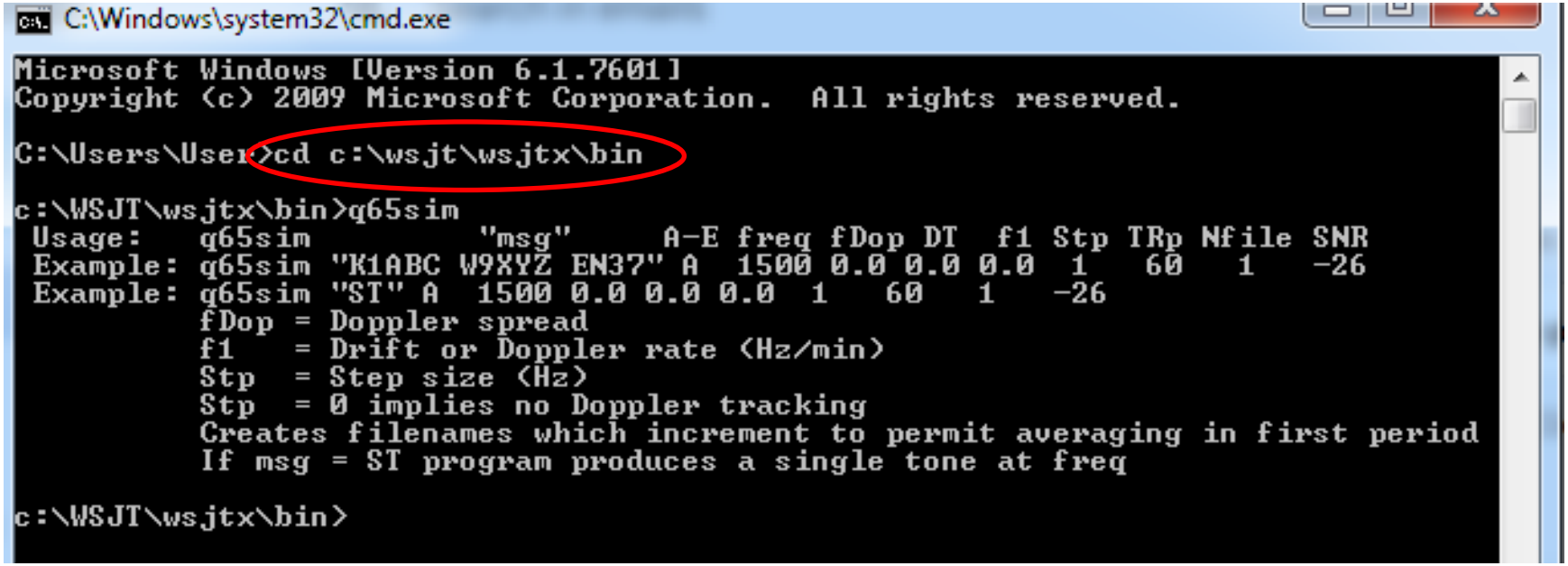


You can use these equations in a spreadsheet, which allows you to calculate the decoding threshold of any of three submodes listed above at a particular value of spreading, rather than interpolating the value from the graph.

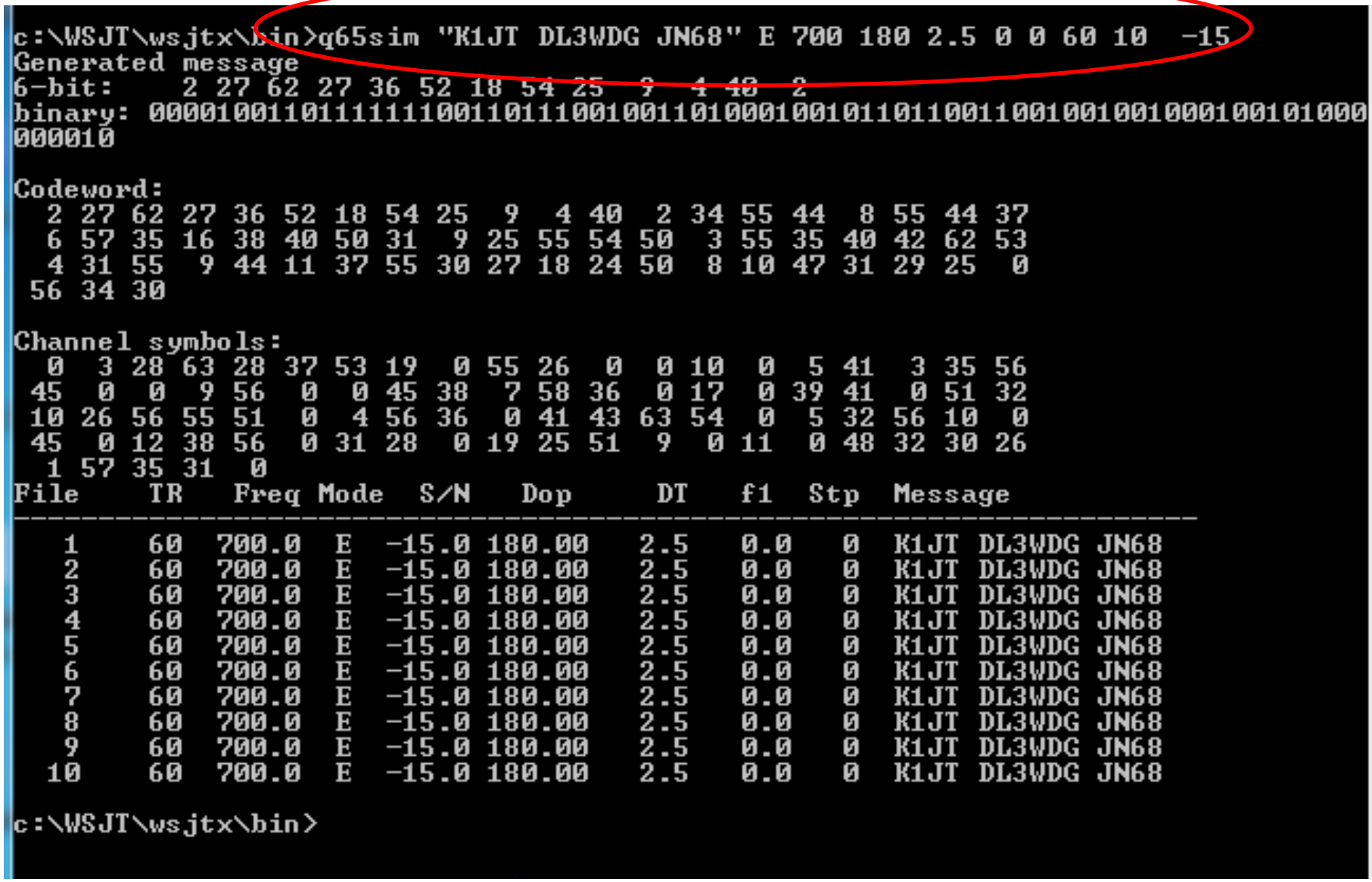
y = decode threshold in dB
x = Doppler spread in Hz

Using q65sim.exe

Open a Command window, eg on Win7 type cmd into the windows search box, or select CMD app in Win10. Enter commands as shown below (assumes WSJT-X is instelled in c:\wsjt).:

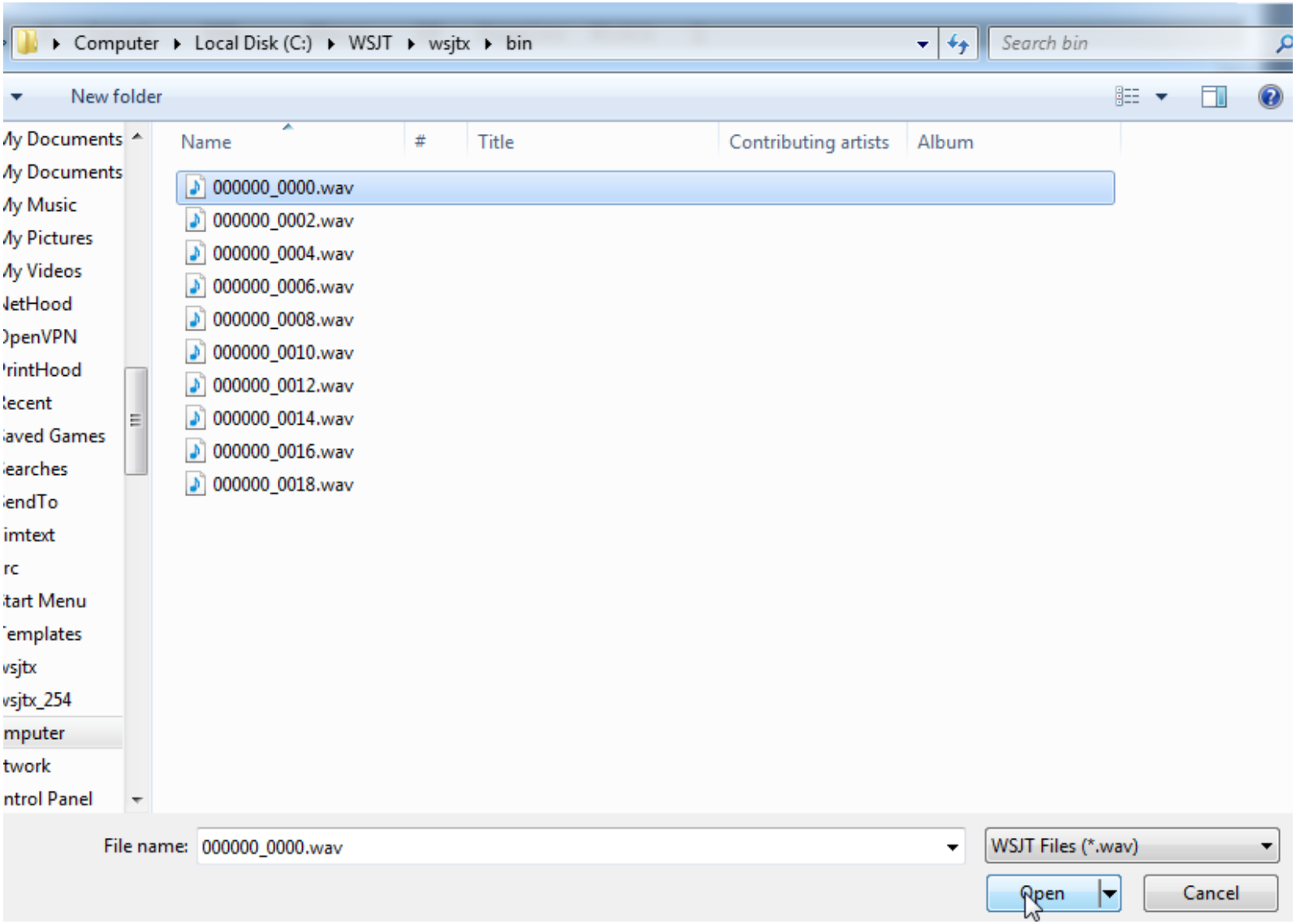


Then type in the command (or copy/paste text at bottom of next slide) to generate the messages – see next slide to see the command and the response from the program. Once the simulator has run, start WSJT-X, and use File->Open and navigate to the generated wave files and play them back – see following slides. [Each wave file has different pseudo random noise to simulate the real world.] Wave file numbering is consistent with messages in the even period, and averaging will work on them as normal. Example message has sufficient S/N to decode without AP.

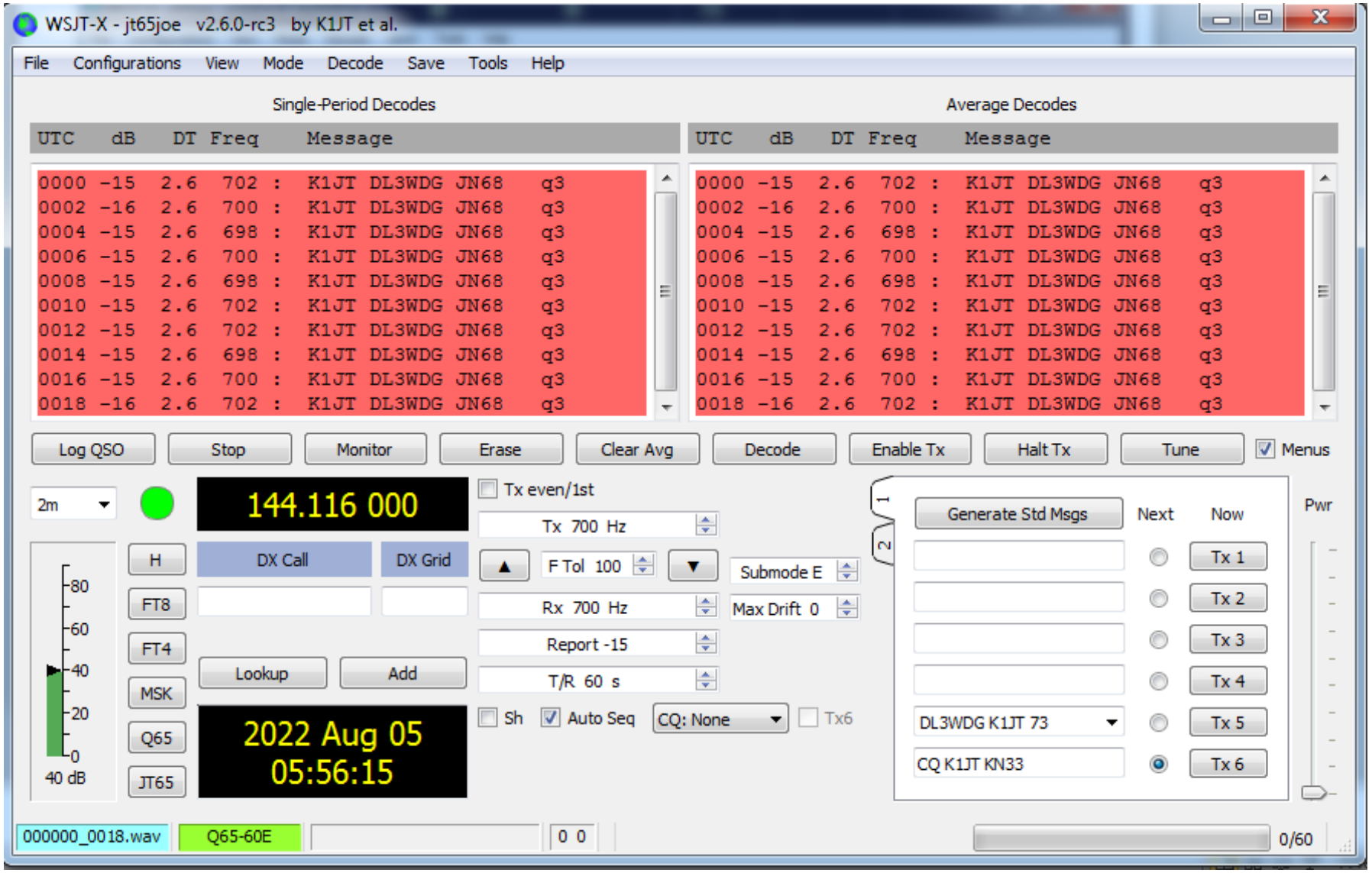


q65sim "K1JT DL3WDG JN68" E 700 180 2.5 0 0 60 10 -15

Q65sim – contd , play back files



Q65sim – contd - result



Links to further information

https://physics.princeton.edu/pulsar/k1jt/Q65_Quick_Start.pdf

https://physics.princeton.edu/pulsar/k1jt/wsjtx.html

https://physics.princeton.edu//pulsar/k1jt/Release_Notes.txt

https://physics.princeton.edu/pulsar/k1jt/WSJTX_2.5.0_MAP65_3.0_Quick_Start.pdf

https://bobatkins.com/radio/EME-echoes.html

https://bobatkins.com/radio/Q65-basics.html

https://bobatkins.com/radio/Q65_step_size_drift_compensation.html

Updates to this presentation (Google Drive)

Updates to this presentation (One Drive) !!!! Needs uploading and editing link

Many thanks to KA1GT, DL4KGC and K1JT for reviewing the presentation, and for their very useful suggestions!